Granular-Fluid Interactions Near the Seabed

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Award # N00014-91-J-1051 (Core); N00014-97-1-0370 (DURIP);
N00014-97-1-0622 (AASERT)

LONG-TERM GOAL

The long term goal is to develop a model which will predict local sand transport and bathymetric change due to waves and currents under time-varying conditions.

SCIENTIFIC OBJECTIVES

Accomplishment of the long-term goal will require significant improvement of our understanding of the relationships between hydrodynamics and sediment motion near the seabed, as well as the development of models derived from our understanding of the relevant physical processes. An accurate prediction of local bedforms is necessary in order to describe the mixing processes which effect both the hydrodynamics and the sediment motion. A related objective is to characterize and predict the suspended sediment concentration in terms of the reference concentration and a vertical distribution function. This requires coupling between hydrodynamic forcing, bedform response and feedback, bedload sediment transport response, and the suspended sediment response.

APPROACH

A combination of experimental observations and model development is being pursued simultaneously. Field observations of nearbed suspended sediment and hydrodynamics provide a basis for the discovery of phenomena and development of models. Model development is focusing on the coupling of bedload to suspended load in order to describe the reference concentration, the description of vertical mixing processes which determine the structure of near bed sand suspension under waves, and the prediction of bedforms from local hydrodynamic and sediment characteristics.

WORK COMPLETED

Field measurements have obtained at Duck, North Carolina over the past several years. Data were collected under a variety of conditions, including storm and storm recovery periods. The 1994, 1995, and 1996 data have undergone quality control, calibration, and analysis. A new multi-element transducer array (MTA, see Jette and Hanes, 1997), designed to measure bedforms, was deployed at Duck along with a new Littoral Sedimentation Processes Measurement System in October, 1996, and September-November, 1997. The MTA allows the measurement of bedform geometry with 2 to 3 millimeter vertical resolution and centimeter horizontal resolution over a profile length of 2.5 meters. The new measurement system also included multi-frequency acoustic backscatter sensors to measure suspended sediment concentration, a rotating side scan sonar to measure bedforms, an acoustic Doppler velocimeter to measure fluid velocity, and an underwater video camera pointed downward toward the bed.

Theoretical development of a granular-flow based model of sheet-flow sand transport has been developed in collaboration with Dr. James Jenkins. The theory includes grain-fluid interactions affecting the momentum and energy transport.

RESULTS

We obtained numerous measurements of small scale bedforms at Duck in July 1995 and October, 1996. These bedforms have been classified as either small scale ripples with ripple wavelengths less than 40 cm, or large scale ripples with wavelengths above 40 cm. Sometimes both scales of bedforms are superimposed.

Small scale ripple dimensions relate to the local mobility number. For example, Figure 1 shows measurements of the small scale ripple along with a simple curve fit based upon mobility number. Small scale ripples were sometimes found to flatten and reform in response to wave groups. Figure 2 shows migrating small scale ripples which are flattened during a large wave group, and then reform quickly under smaller waves. Mobility number was also found to be a useful parameter to predict the flattening and reformation of small scale ripples.

The concentration of suspended sediment was found to be related to the square of the local cross-shore fluid velocity, which is a measure of the kinetic energy of the wave induced fluid motion. For example, the co-spectrum of sediment concentration and the square of the cross-shore velocity indicates significant coherence across a large range of frequencies. The suspended sediment concentration spectrum is shown in Figure 3, where the bold line indicates regions of coherence between concentration and the square of the cross-shore velocity exceeding 0.6. This figure indicates a strong correlation between suspended sediment concentration and wave groups across a broad range of frequencies. There is significant suspension at infra-gravity frequencies (Beach and Sternberg, 1991) which correlates with the envelope of wave groups (Hanes, 1991).

In the area of bedload modeling, the development of a theory for intense bedload sand transport under unidirectional flow provides the concentration profile within the bedload layer. While further work is required for application under waves, this work provides a basis for the linking of bedload processes to suspended load processes, and the prediction of a reference concentration.

IMPACT/APPLICATION

The connections between small scale and large scale sedimentation processes are important in order to develop a comprehensive understanding of nearshore sedimentation processes, and an ability to model bathymetric change. Our research provides new information on small scale processes which will allow these connections to be discovered and verified.

TRANSITIONS

Our instrumentation was deployed off the Sensor Insertion System at SandyDuck in collaboration with the U.S.A.C.E. Field Research Facility and the Coastal Hydraulics Laboratory.

Chris Jette, the graduate student who developed the MTA has started a company to commercially produce the instrument.

RELATED PROJECTS

The NSF Center for Particle Science and Technology is supporting our research on the fundamental behavior of flowing particulate systems. This research is highly relevant to our modeling of nearshore bedload sediment transport.

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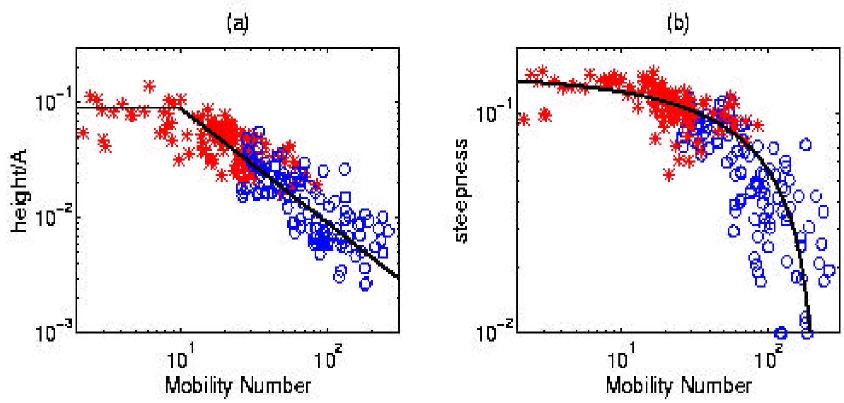

Figure 1. Measured (a) Nondimensional ripple height (η/A) and (b) ripple steepness for SIS95 (*) and SIS96 (o) data with the new model curves. Mobility Number and semi-excursion are calculated from the significant near-bottom orbital velocity and significant orbital diameter (from Jette, 1997).

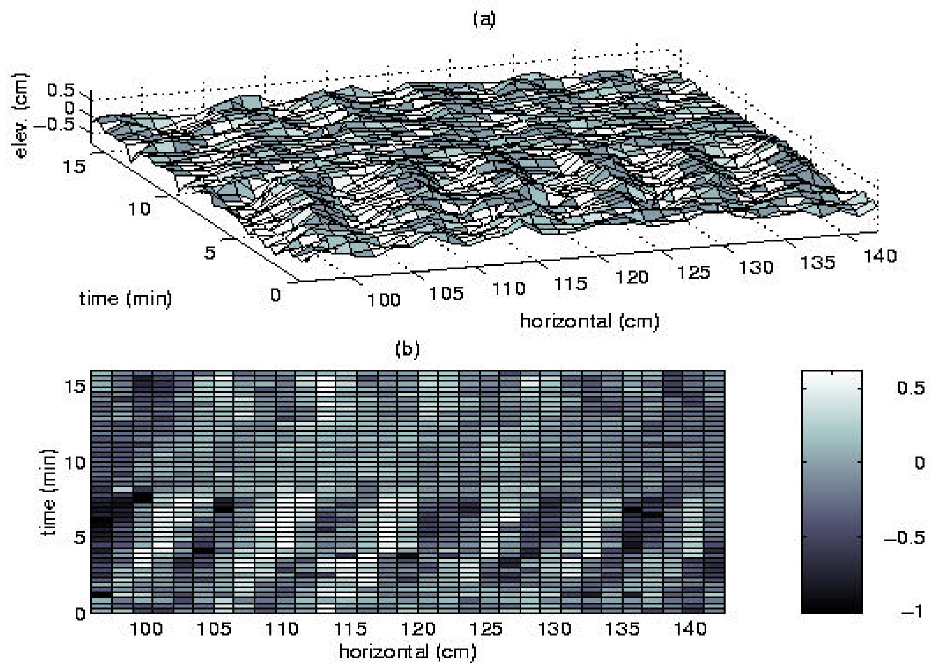

Figure 1. Small scale bedform profiles for run 16. Mesh plot of bedform profiles (a) with time on the y-axis. Surface plot of bedform profiles (b) with time on the y-axis, horizontal distance on the x-axis, and vertical elevation as indicated by the colorbar in centimeters (From Jette, 1997).

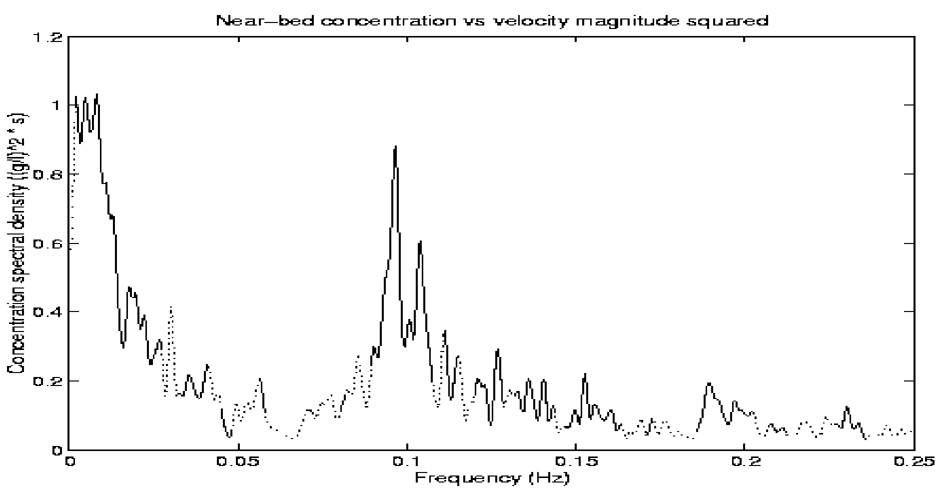

Figure 3. Concentration energy spectrum (dotted) with areas of coherence > 60% indicated by a solid line (from Thosteson, 1997).